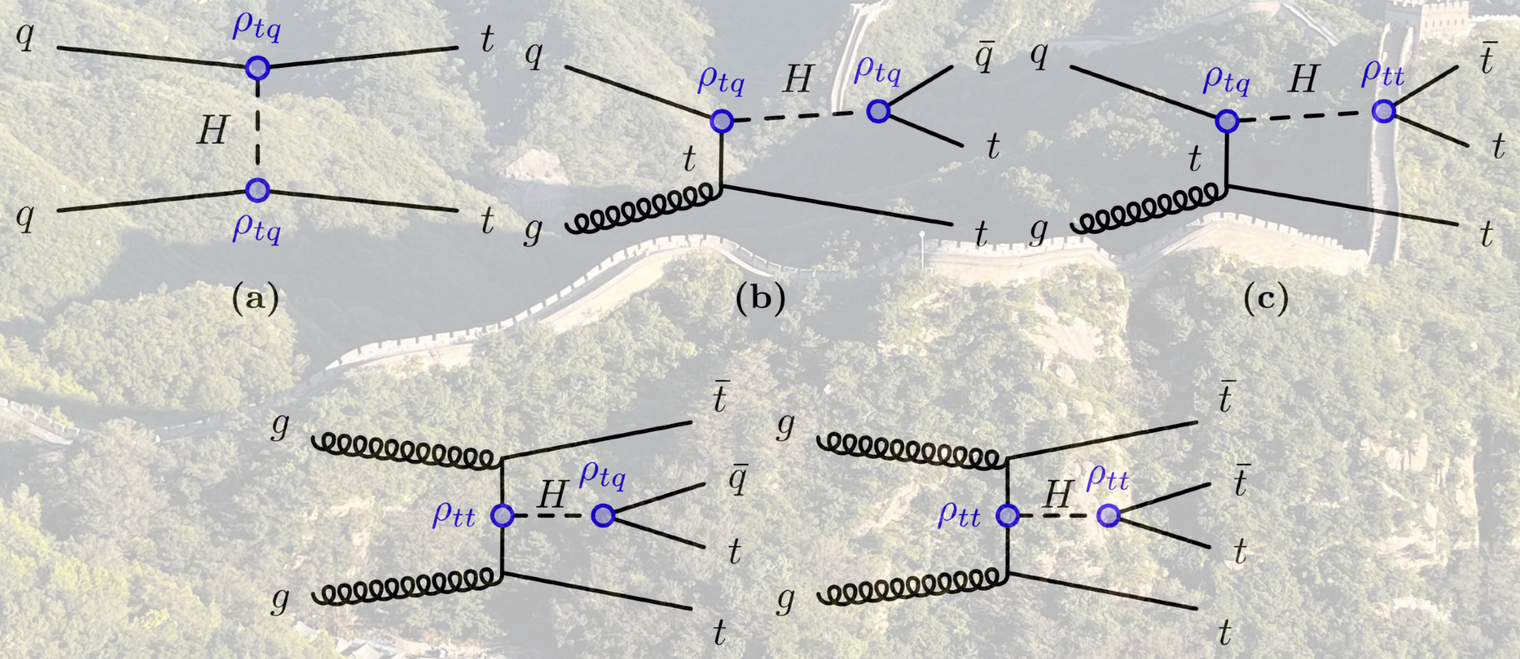
Interference effects from flavour physics in the General 2HDM and ATLAS multi-top probes



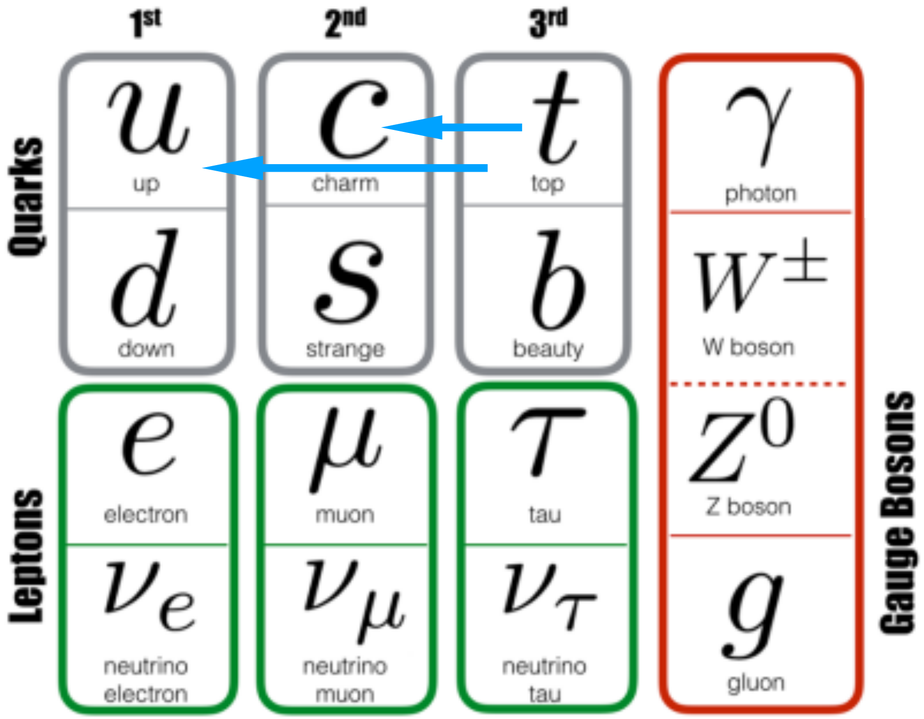
17th International Conference on Heavy Quarks and Leptons (HQL 2025), Beijing

Cristian Sierra, 2025年09月16日

General 2HDM

Adding a second Higgs doublet is one of the simplest extensions of the SM

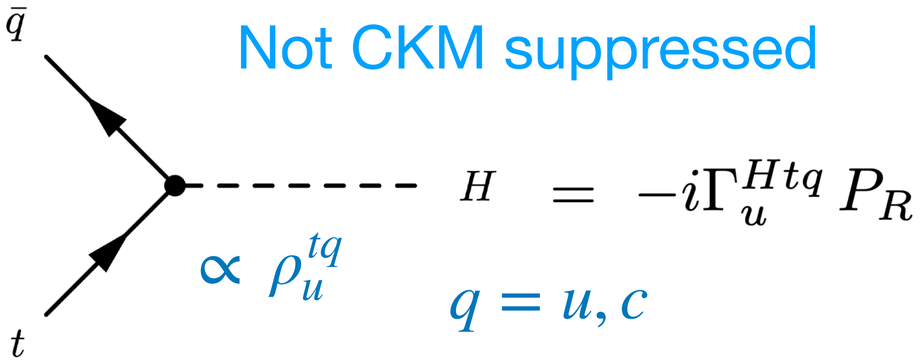
$$\Phi_i = \begin{pmatrix} \phi_i^+ \\ \frac{1}{\sqrt{2}}(v_i + \xi_i + i\eta_i) \end{pmatrix}, \quad i = 1, 2.$$



In the mass basis, the Yukawa Lagrangian has the following flavour violating couplings

$$-\mathcal{L}_{Yukawa} = \bar{u}_b \left(V_{bc} \rho_d^{ca} P_R - V_{ca} \rho_u^{cb*} P_L \right) d_a H^+ + \bar{\nu}_b \rho_\ell^{ba} P_R l_a H^+ + \text{h.c.}$$
$$+ \sum_{f=u,d,\ell} \sum_{\phi=h,H,A} \bar{f}_b \Gamma_f^{\phi ba} P_R f_a \phi + \text{h.c.},$$

$$\Gamma_f^{Hba} \equiv \frac{\bar{M}_f^{ba}}{v} c_{\beta\alpha} - \frac{1}{\sqrt{2}} \rho_f^{ba} s_{\beta\alpha}$$



Not CKM suppressed

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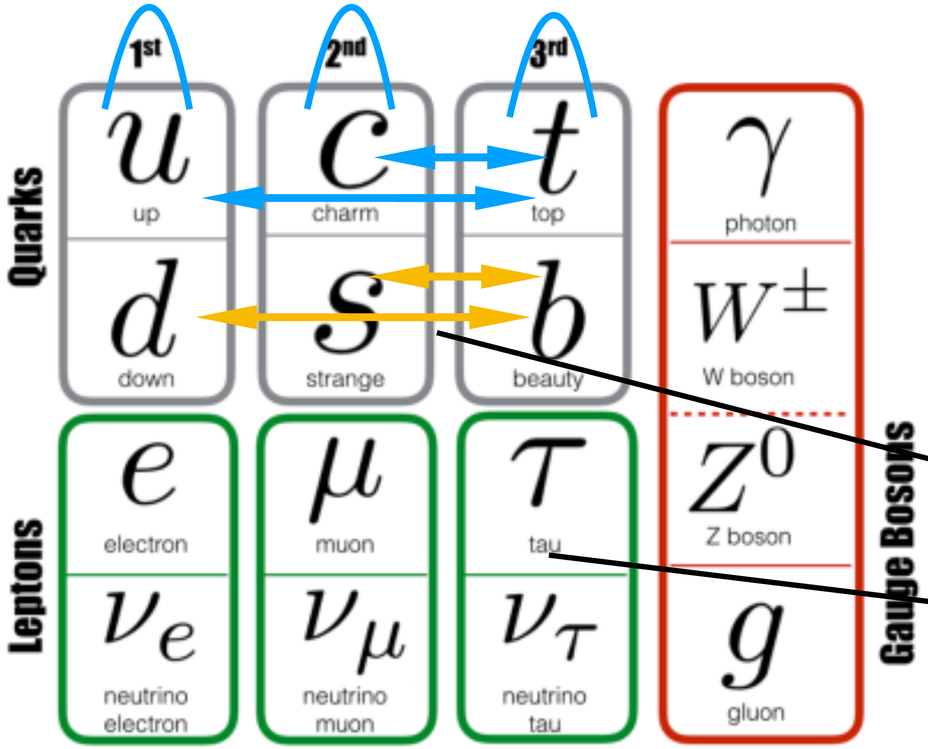

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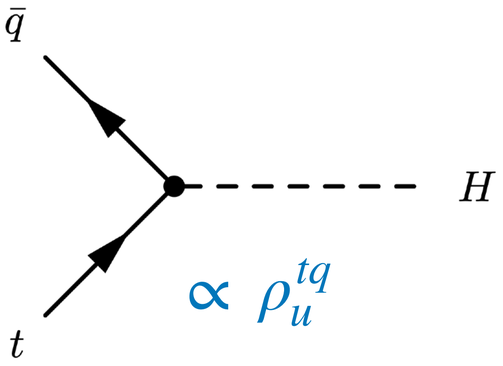
$$\rho_u = \begin{pmatrix} \rho_u^{uu} & \rho_u^{uc} & \rho_u^{ut} \\ \rho_u^{cu} & \rho_u^{cc} & \rho_u^{ct} \\ \rho_u^{tu} & \rho_u^{tc} & \rho_u^{tt} \end{pmatrix}$$

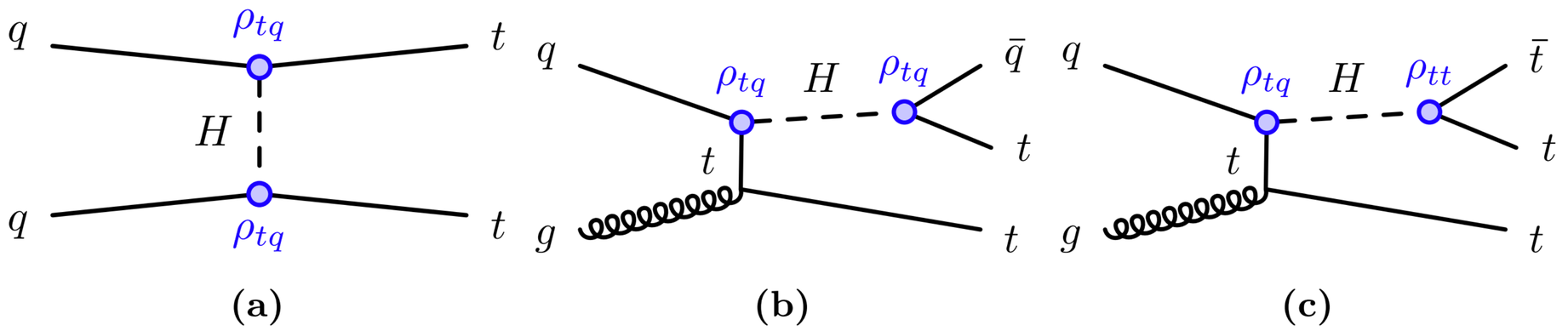
Very suppressed at tree level, only non-zero can be ρ_d^{bb}.

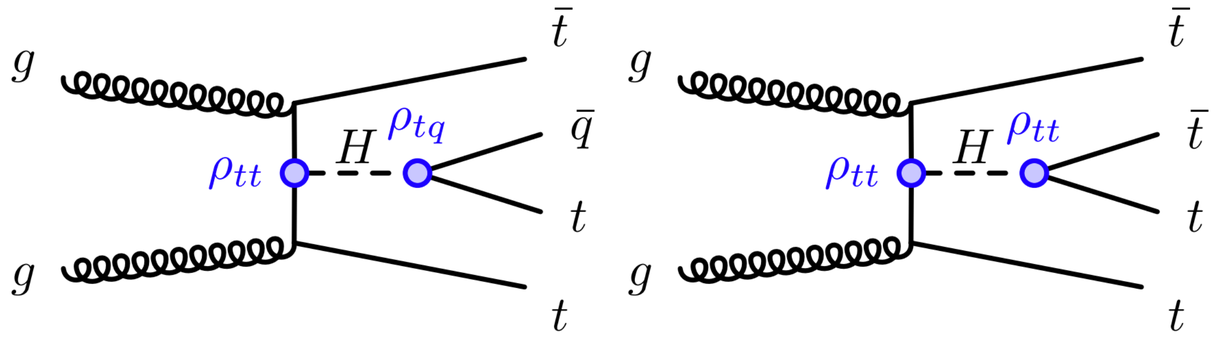
Only non-zero are $\rho_\ell^{\tau\tau}$ and possibly $\rho_\ell^{\mu\tau,\tau\mu}$.

Multi-lepton + jets@ATLAS

ATLAS did a search for heavy Higgs bosons with FV couplings with the top quark https://arxiv.org/pdf/2307.14759







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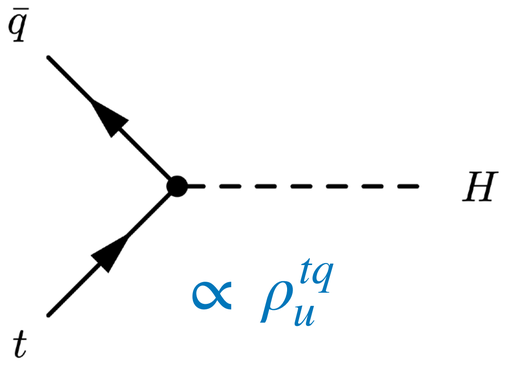
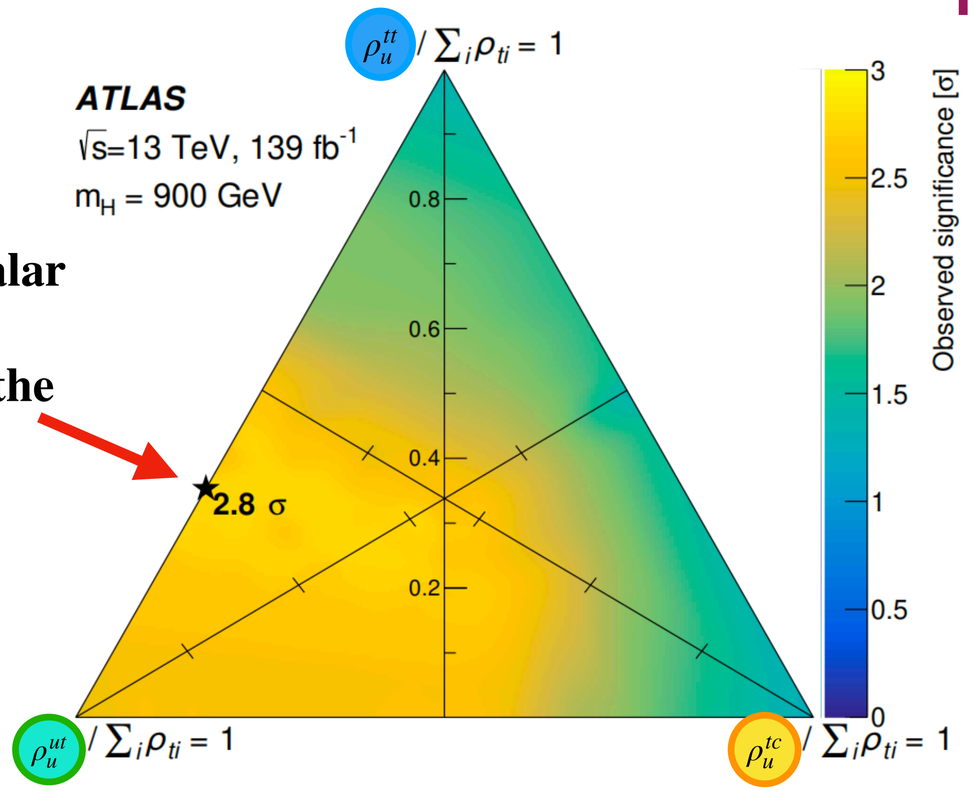


Observed significance for a heavy scalar with a mass of 900 GeV as a function of the three couplings normalised to the sum of the couplings



Motivation for this study:

ρ_{tt}=0.6, ρ_{tc}=0.0, and ρ_{tu}=1.1

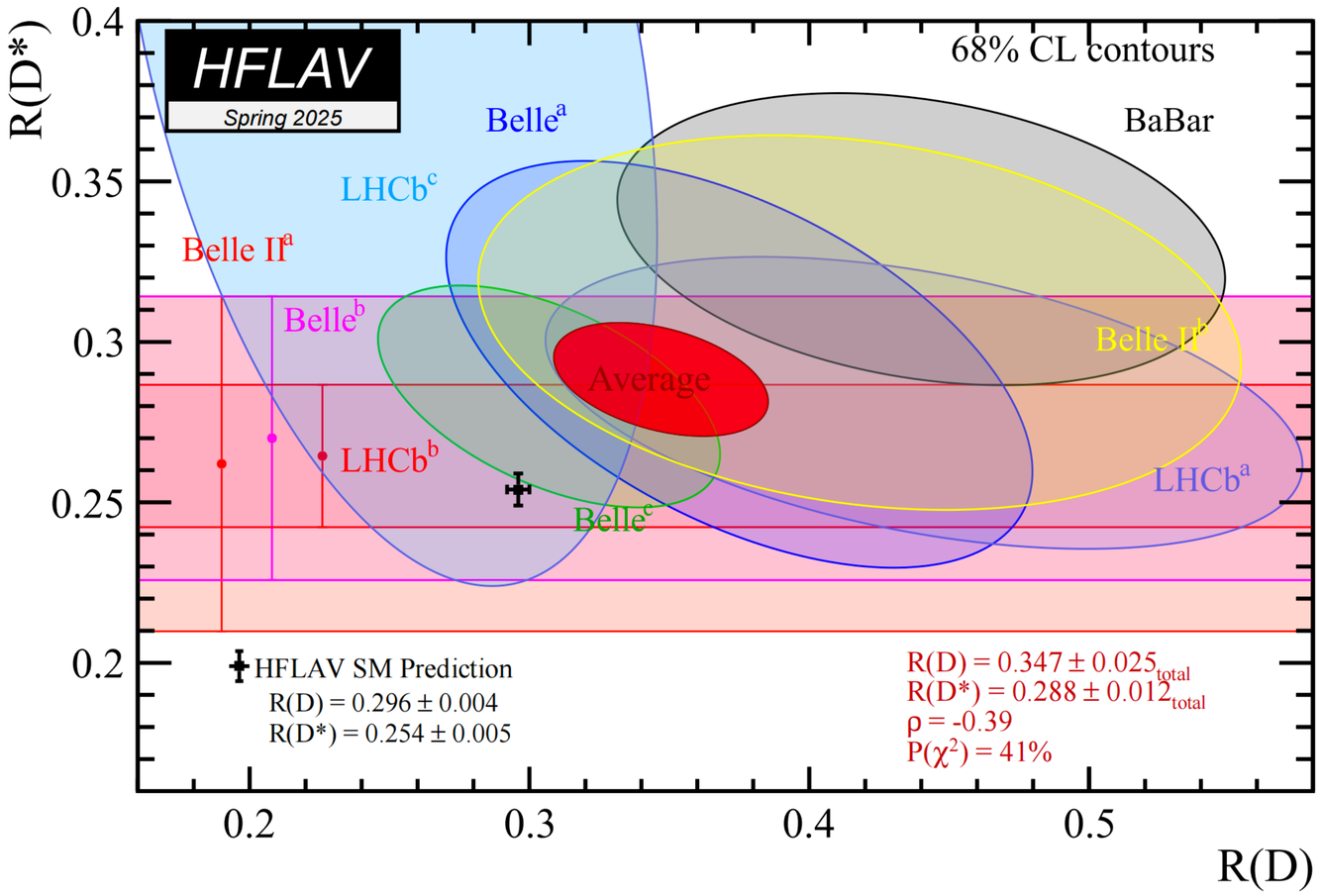
Fit with no flavour constraints!

- ρ_u^{ut} seems to big, might not respect flavor constraints.
- Non-zero ρ_u^{tc} is needed for Explaining the charged current anomalies.

Flavour constraints

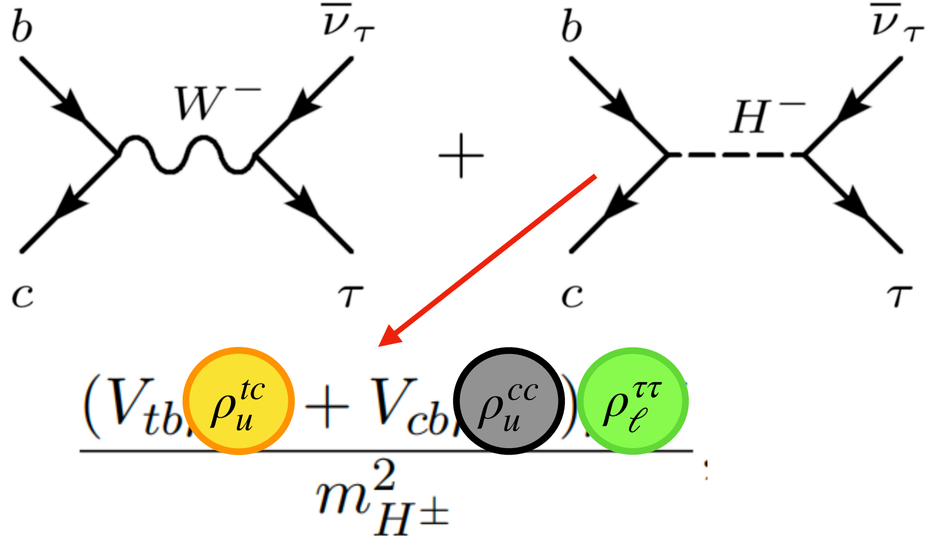
$$R_D = \frac{\Gamma(\overline{B} \to D\tau\overline{\nu})}{\Gamma(\overline{B} \to Dl\overline{\nu})} \qquad R_{D^*} = \frac{\Gamma(\overline{B} \to D^*\tau\overline{\nu})}{\Gamma(\overline{B} \to D^*l\overline{\nu})}$$

$$R^{\text{exp}}_{D^{(*)}} > R^{\text{SM}}_{D^{(*)}} \quad \text{at } 3.8\,\sigma$$



Taken from Moriond 2025

Possible interference with NP?



$$\frac{(V_{tb}\rho_u^{tc} + V_{cb}\rho_u^{cc})\rho_\ell^{\tau\tau}}{m^2_{H^\pm}}$$

Non-zero ρ_u^{tc} and $\rho_\ell^{\tau\tau}$ are needed.

Flavour constraints

$$\rho_u = \begin{pmatrix} \rho_u^{uu} & \rho_u^{uc} & \rho_u^{ut} \\ \rho_u^{cu} & \rho_u^{cc} & \rho_u^{ct} \\ \rho_u^{tu} & \rho_u^{tc} & \rho_u^{tt} \end{pmatrix}$$

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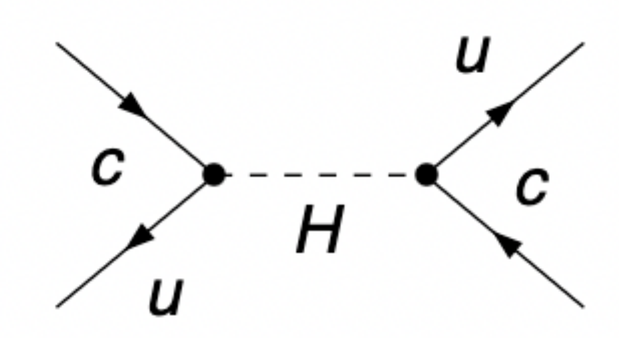
- $D^0 - \bar{D}^0$ mixing at tree level.



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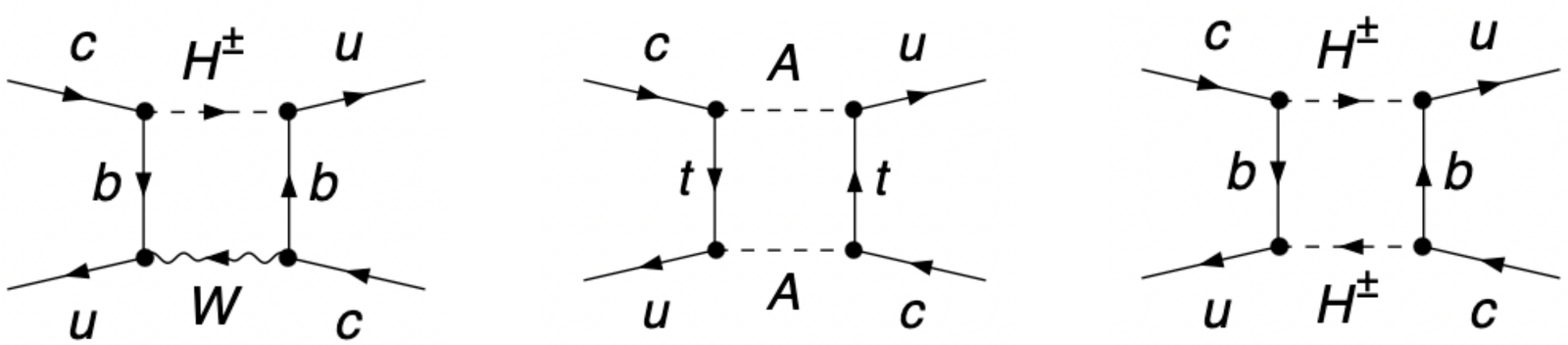
- $D^0 - \bar{D}^0$ mixing at one-loop.



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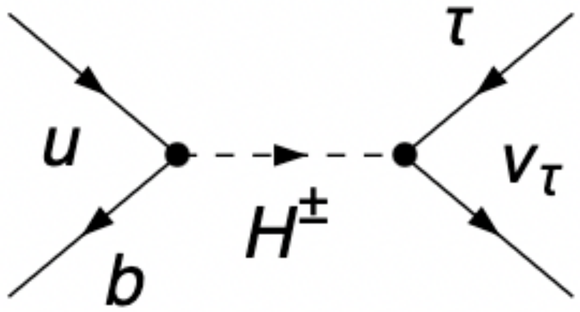
- $D^0 - \bar{D}^0$ mixing at tree level.
- $D^0 - \bar{D}^0$ mixing at one-loop.
- $B_u \to \tau\nu$ at tree level.



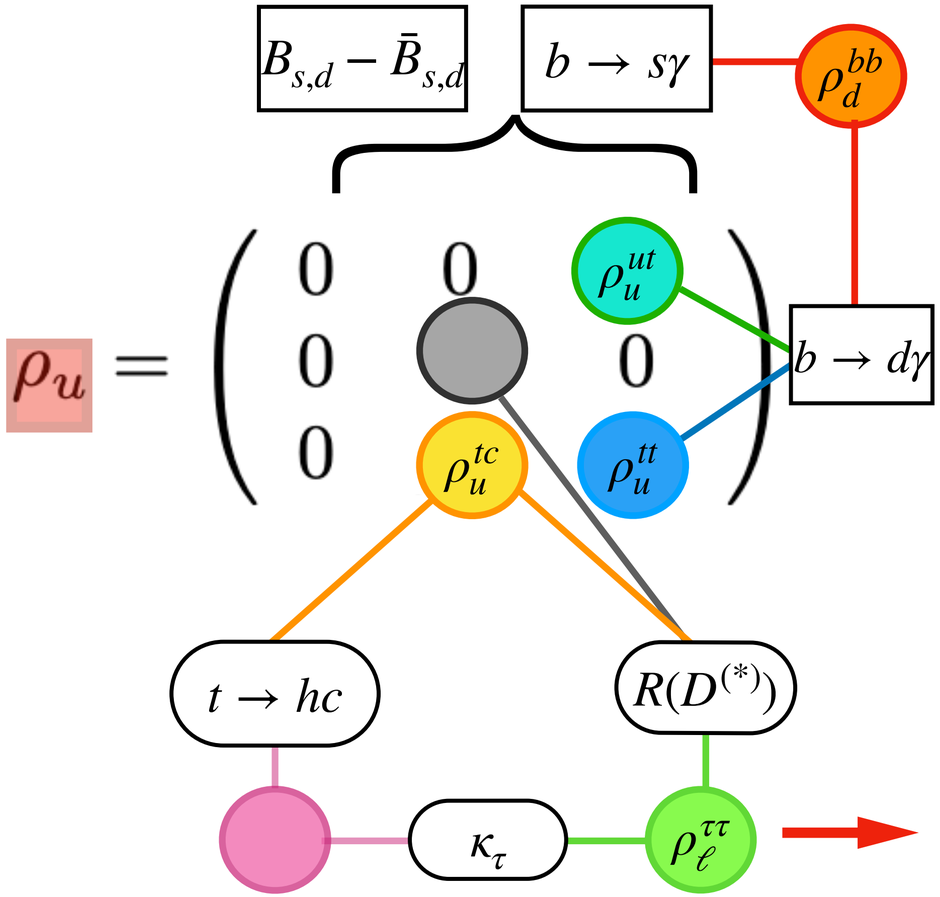
Flavour constraints

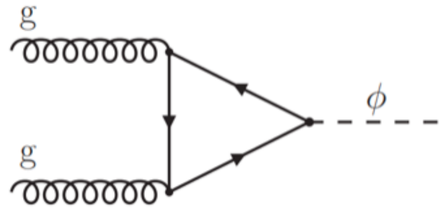
- Nested sampling scan using Bayesian inference.
- Resultant parameter space from flavour constraints.

$$m_A = m_{H^\pm}$$

$$m_A - m_H = 50\,\text{GeV}$$

(Constrain all four couplings)



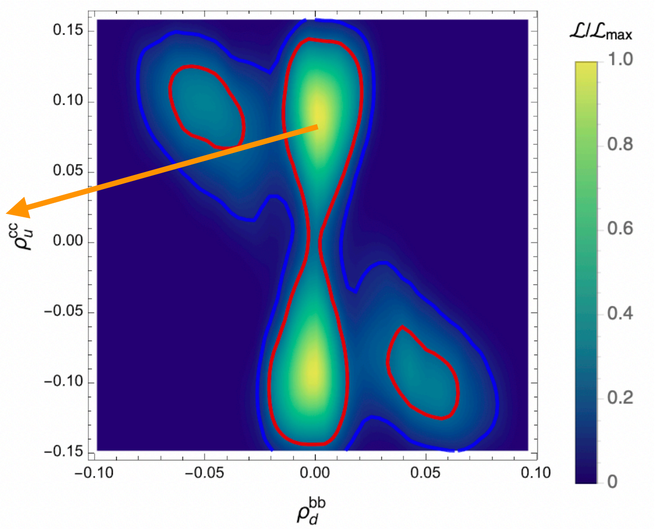


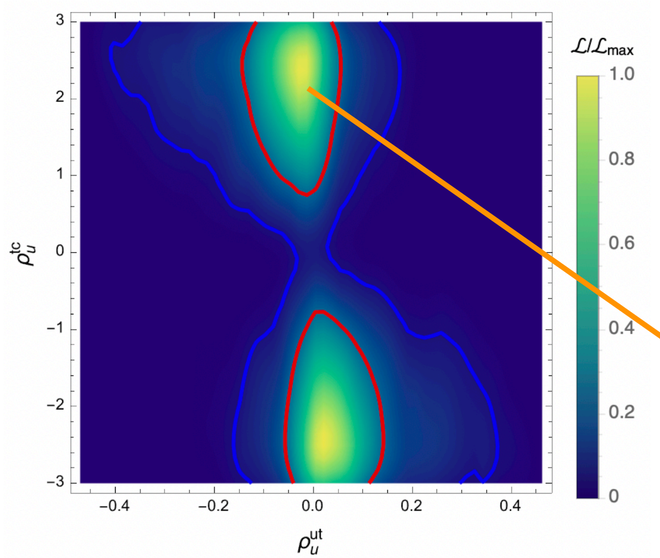
$$\sigma(gg \to \phi \to \tau^+\tau^-) = \sigma(gg \to \phi) \cdot \text{BR}(\phi \to \tau^+\tau^-)$$

- *Need to include multi-tau decays from CMS.*
- *eEDM constrain the imaginary part of* $\rho_\ell^{\tau\tau}$.

Results

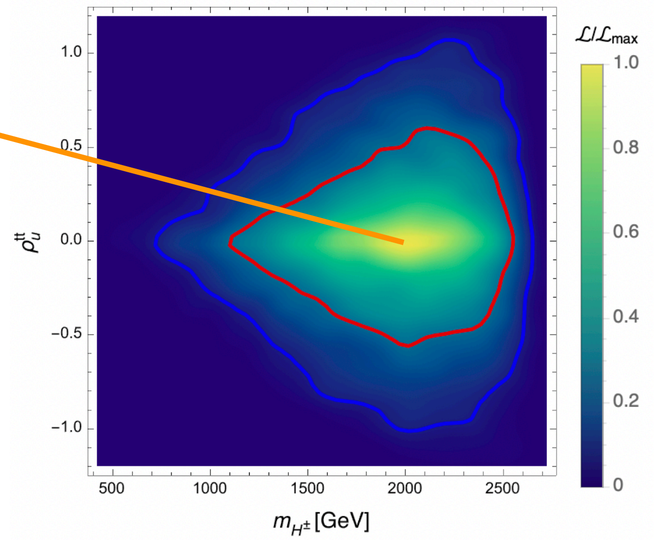
Non-zero best fit point for ρ_u^{cc} and small ρ_d^{bb}

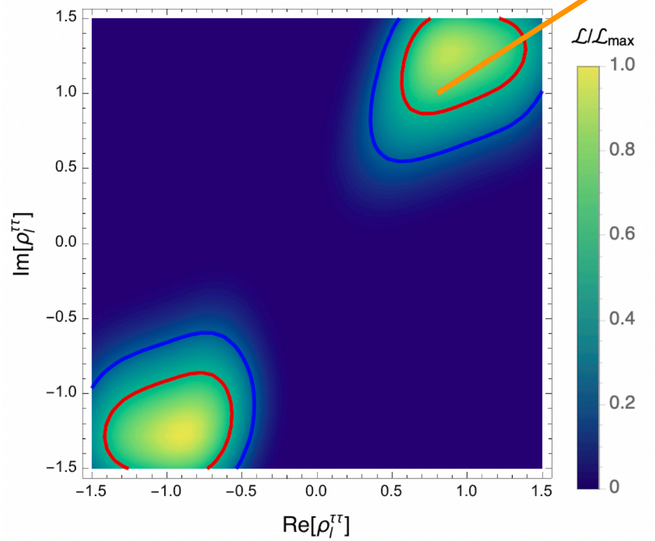




Non-zero ρ_u^{tc} and $\rho_\ell^{\tau\tau}$

Small ρ_u^{tt} and large masses

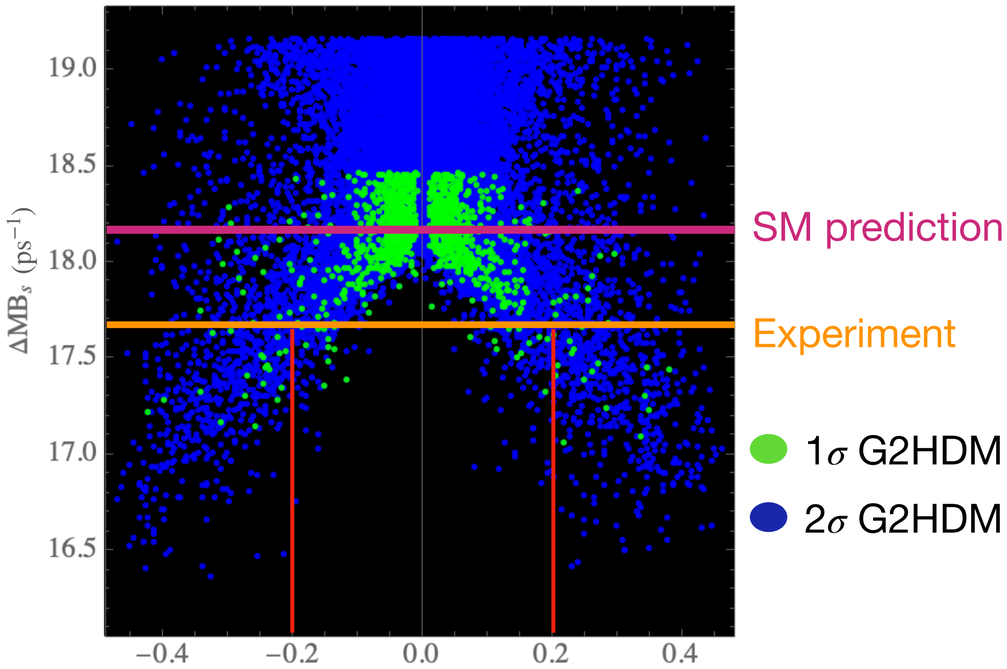




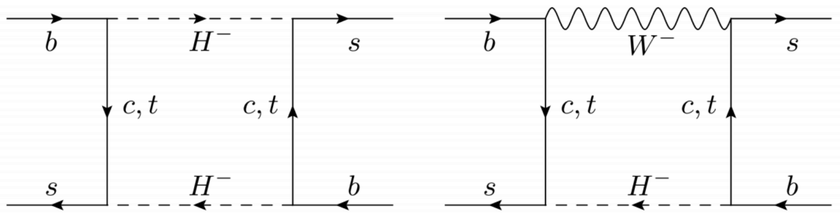
Results

SM has large uncertainties! ΔM_{B_s}=(18.2±0.7)ps^{-1}

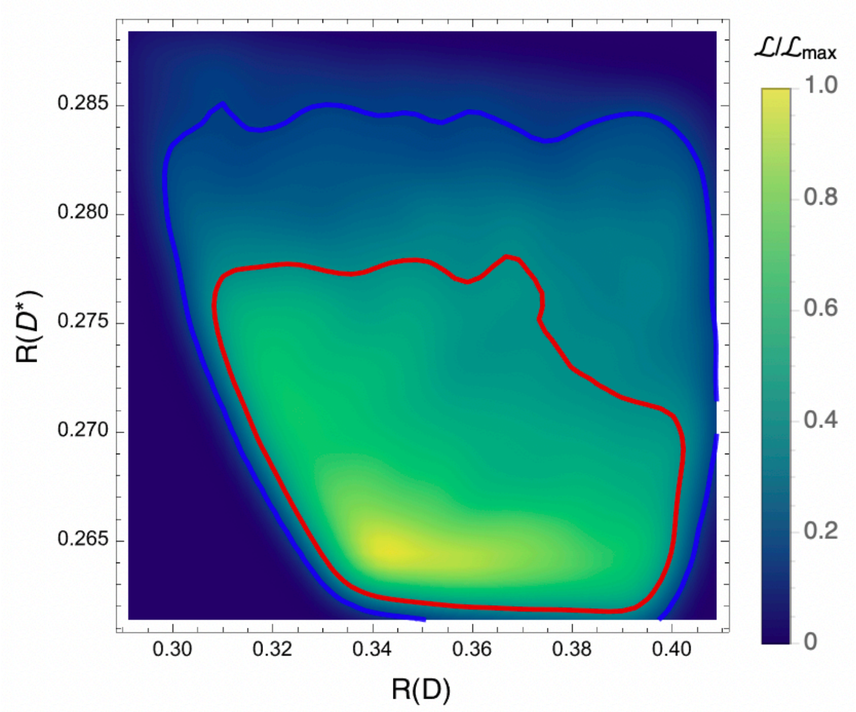
Exp.measurement is very precise! (17.766±0.006)ps^{-1}

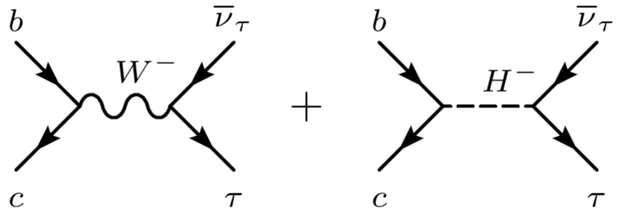


ρ_u^{ut} ~|0.2|



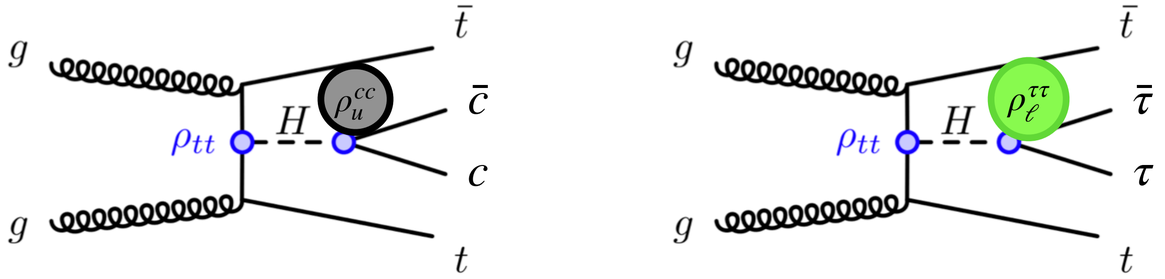
Fits simultaneously $R(D^*)$ ratios at 1σ with non-zero ρ_u^{tc} and $\rho_\ell^{\tau\tau}$





Summary

- General 2HDM offers FV couplings with rich phenomenology.
- ATLAS used the model to study multi-top production for the first time.
- Computed constraints for quark couplings from tree and loop level observables.
- Interferences in meson oscillations along different up-like quark couplings improve the fit to ΔM_{B_s}.
- The resultant parameter space can fit the $R(D^*)$ ratios at 1σ.
- Those constraints can be used for new analysis at ATLAS for multi-top decays including new modes.



谢谢！

Flavour constraints